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EVALUATION OF RADIUM CONTAMINATION IN AIRCRAFT INSTRUMENT REPAIR FACILITIES

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Santa Fe, New Mexico

May 1969

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EVALUATION OF RADIUM CONTAMINATION IN AIRCRAFT INSTRUMENT REPAIR FACILITIES

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EVALUATION OF RADIUM CONTAMINATION IN AIRCRAFT INSTRUMENT REPAIR FACILITIES

ABSTRACT

Dial-stripping operations in aircraft instrument repair facilities have caused alpha-particle contamination levels exceeding 100,000 disintegrations per minute/100 cm^2 in these facilities, with up to 1,650,000 disintegrations per minute/100 cm^2 in one facility. Existing radium control programs in these facilities are inadequate. Instrumentation, training, and assistance for decontamination and waste disposal are needed in most of the facilities surveyed. Two workers in the facility with the highest levels of contamination had body burdens in excess of 40 percent of the maximum permissible body burden of radium, and a third worker had a possible body burden of about 14 percent. Workers in all other facilities included in the study had less than 10 percent of the maximum permissible body burden. A recommended control program for aircraft instrument repair facilities is described.

Decontamination of one aircraft instrument repair facility was conducted to evaluate decontamination methods for floors, benches, and equipment. The final survey of the facility showed that alpha-particle contamination levels of floors and tables were generally below 2,500 disintegrations per minute/100 cm^2 fixed and 30 disintegrations per minute/100 cm^2 removable. The average decontamination factors achieved were 25 for floors, 100 for highly contaminated benches, and 15 for equipment.

Methods for decontaminating instrument parts and for dial stripping were also evaluated. A procedure for dial stripping is recommended. Decontamination of instrument parts is considered to have marginal value because of the generally low levels of contamination.

EVALUATION OF RADIUM CONTAMINATION IN AIRCRAFT INSTRUMENT REPAIR FACILITIES

The research aspects of the program described in this report were sponsored under U.S. Public Health Service Contract No. 86-67-66 with Eberline Instrument Corporation Santa Fe, N. Mex. Mr. Eric L. Geiger, Eberline Instrument Corp., was project leader for this study, and Mr. Gail D. Schmidt, Bureau of Radiological Health, was the project officer.

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The National Center for Radiological Health was reorganized December 1968. It is now the Bureau of Radiological Health, with Dr. Raymond T. Moore, as the Acting Director.

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FOREWORD

The Bureau of Radiological Health, formerly the National Center for Radiological Health, continues to carry out a national program designed to reduce the exposure of man to hazardous ionizing and nonionizing radiation.

Within the Bureau, the Division of Medical Radiation Exposure deals with 1) the reduction of unproductive ionizing radiation exposure of patients, workers, and others exposed by the use of X-rays and other machine produced ionizing radiation, radioactive materials and radiopharmaceuticals, and 2) the improvement of radiological "systems" and methodology in the healing arts.

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I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

Raymond T. Moore

Raymond T. Moore, M.D.
Acting Bureau Director

PREFACE

Radium luminous dials were used in the Navy flying boat NC-4, which flew across the Atlantic in 1919. Since that time, radium luminous compounds have been used extensively on aircraft instruments, particularly on military aircraft during World War II and immediately thereafter.

Many of these instruments, declared surplus by the U.S. Department of Defense, are being utilized by private industry for repair parts and original installation in light aircraft. Significant contamination has been observed in those facilities that disassemble and repair radium dial instruments. The highest levels were observed in the facilities that conduct dial stripping and refinishing operations.

Approximately 400 facilities are certified by the Federal Aviation Agency to repair instruments for flight use. Facilities which strip dials, but do not repair flight instruments, do not require Federal Aviation Agency certification and must be located by personal contact. These facilities do not have radiological health competence and require assistance in decontamination, waste disposal, and establishment of a radiation protection program.

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ABSTRACT

Dial-stripping operations in aircraft instrument repair facilities have caused alpha-particle contamination levels exceeding 100,000 disintegrations per minute/100 cm^2 in these facilities, with up to 1,650,000 disintegrations per minute/100 cm^2 in one facility. Existing radium control programs in these facilities are inadequate. Instrumentation, training, and assistance for decontamination and waste disposal are needed in most of the facilities surveyed. Two workers in the facility with the highest levels of contamination had body burdens in excess of 40 percent of the maximum permissible body burden of radium, and a third worker had a possible body burden of about 14 percent. Workers in all other facilities included in the study had less than 10 percent of the maximum permissible body burden. A recommended control program for aircraft instrument repair facilities is described.

Decontamination of one aircraft instrument repair facility was conducted to evaluate decontamination methods for floors, benches, and equipment. The final survey of the facility showed that alpha-particle contamination levels of floors and tables were generally below 2,500 disintegrations per minute/100 cm^2 fixed and 30 disintegrations per minute/100 cm^2 removable. The average decontamination factors achieved were 25 for floors, 100 for highly contaminated benches, and 15 for equipment.

Methods for decontaminating instrument parts and for dial stripping were also evaluated. A procedure for dial stripping is recommended. Decontamination of instrument parts is considered to have marginal value because of the generally low levels of contamination.

Representative products and manufacturers are named for identification only, and listing does not imply endorsement by the Public Health Service and the U.S. Department of Health, Education, and Welfare.

EVALUATION OF RADIUM CONTAMINATION IN AIRCRAFT INSTRUMENT REPAIR FACILITIES

INTRODUCTION

United States total production of radium has amounted to about 200 grams and about 1,800 grams have been imported (1). Estimates place the quantity of radium used during World War II as luminous compounds for instruments, dials and markers at several hundred grams (2). For many years such instruments and devices containing radium were not controlled. In June 1950, the Department of the Army issued a technical bulletin that has since served as a guide for radium control in military facilities (3). As the hazards associated with radium became better known, its use has been discouraged; however, a vast number of radium-bearing instruments have found their way into the public domain, having been disposed of by the military either because of obsolescence or as surplus (2). Some of these, in turn, have become concentrated in the light aircraft industry where they are widely used for original installations or as replacement parts (fig. 1). These instruments are not labeled as to their radium content, and few of the workers in these facilities are aware that a radiation hazard exists. These facilities have been certified by the Federal Aviation Agency to repair aircraft instruments, but no provision for radium control is included in the certification. The Federal Aviation Agency recently issued a circular advising repair stations of the radiation hazards associated with the repair and maintenance of radium dial instruments (4). To update these instruments, dials containing radium are sometimes removed, the old paint stripped from the dial and repainted. These teardown and dial-stripping operations have caused considerable contamination of the facilities. A study of similar situations in

the United Kingdom has shown that luminizing facilities were highly contaminated, and that employee body burdens of radium were elevated in those facilities that had the highest levels of contamination (5).

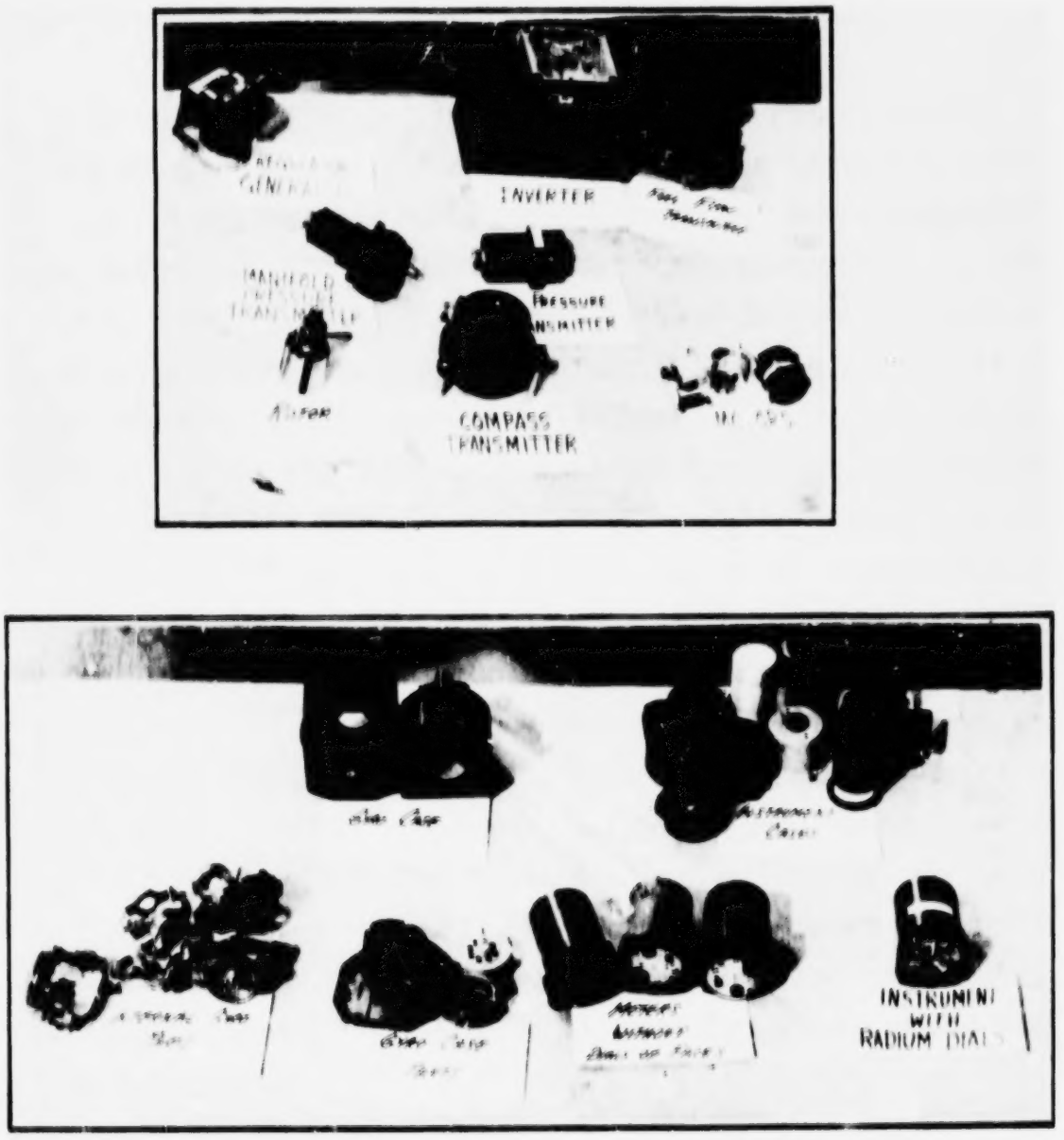

Figure 1. Typical radium dial aircraft instruments and disassembled components

Radium, a naturally occurring radioelement, does not fall under the regulatory authority of the Atomic Energy Commission and is controlled only in those States where appropriate

legislation exists. Until recently, most aircraft instrument repair facilities have operated without any radium control program.

This combination of events has led to the problem of developing a radium control program for the aircraft instrument repair industry that will protect the workers concerned, without overly restricting production. This study of the problem was conducted by Eberline Instrument Corporation, Santa Fe, N. Mex., under U.S. Public Health Service contract No. PH 86-67-66 and with the cooperation and assistance of the Kansas State Department of Health and the Wichita-Sedgwick County Health Department.

Over 75 percent of the light aircraft produced in the United States are fabricated in Wichita, Kans. All but one of the facilities included in this study were located in Wichita. To outline the purpose of this study and to elicit the cooperation of companies doing this type of work, arrangements were made for a meeting between representatives from the companies involved, U.S. Public Health Service, Kansas State Department of Health, Wichita-Sedgwick County Health Department, and Eberline Instrument Corporation. A total of 15 companies voluntarily participated in the study. Participation by these companies involved one or more of the following:

a. Cooperate with Eberline Instrument Corporation and Kansas State Department of Health during surveys of their facilities.

b. Collect wipe samples from contaminated areas at various times to document levels of removable contamination.

c. Schedule personnel for whole-body counting and provide information on exposure history.

d. Issue urine sampling kits to personnel, with instructions, then collect and return the urine samples to the Eberline Instrument Corporation, Santa Fe, N. Mex. for analysis.

e. Issue and exchange beta-gamma film badges and radon film badges.

f. Collect air samples and send them to Santa Fe for analysis.

Specific objectives included:

a. Document and evaluate existing radiation control programs for individuals engaged in aircraft instrument repair facilities.

b. Relate levels of contamination in aircraft instrument repair facilities to the nature and amount of activity performed in each facility and to radium body burdens of individuals working in these facilities.

c. Recommend a radium control program for aircraft instrument repair facilities.

d. Evaluate methods for decontaminating instruments and facilities.

EVALUATION OF THE HAZARDS

CONTAMINATION LEVELS

A total of 15 aircraft instrument repair facilities were surveyed for alpha-particle contamination. The results of these surveys are shown in table 1. Alpha-particle surveys were made with gas–flow proportional counters, Eberline Models PAC-3G Portable Alpha Counter, PAC-4G Portable Alpha Counter, and FM-3G Alpha Floor Monitor. Removable alpha-particle contamination was determined as follows:

a. A tissue (for example, Kleenex or Kimwipe) was folded to a 3- by 3-inch size or smaller, dampened with alcohol, and used to wipe an area of approximately 1 square foot.

b. The tissue was allowed to dry and the short half-life daughters were allowed to decay so that the radioactivity measured would be only radium 226 and associated daughters.

c. The alpha-particle emission rate from the tissue was measured with a large window, gas flow, alpha proportional counter.

Significant amounts of long half-life alpha-particle contamination were found in all cases where dial stripping was being done currently or had been done in the past. Instrument disassembly areas that were not immediately adjacent to the stripping area showed lower levels of contamination, but occasionally wipe samples showed high levels of removable alpha-particle contamination. In at least one facility, high levels of removable alpha-particle contamination could be related to instrument disassembly operations (table 2). Results of wipe samples of the disassembly bench taken after the disassembly of each group of instruments and before any cleanup of the bench are given in Table 2. It is felt that each high value represents contamination from the disassembly of instruments.

Table 1. Maximum radiation and contamination levels measured at various facilities

Facility code and type[a]	Instruments or dials per year	Alpha-particle contamination			Gamma radiation	
		Site	Total (dpm/100cm²)	Removable (dpm/100cm²)	Site	(mr/hour)
A-1	180 in 1967 3,000 in 1966 4 percent contain radium	Table Floor	200,000 100,000	170 270	Hood Stockroom	60 5
B-1	4,000-Repair Stripping Discontinued	Bench Floor	167,000 334,000	2,100 1,000	General	< 2
C-1	30,000 5 percent contain radium	Sink Desk Bench Floor[b]	1,650,000 3,300 330,000 16,500	2,700 500 1,400	Storage Stripping	13 5
D-1	Stripping discontinued	Desk Floor Table	3,300 100,000 > 330,000	500 < 200 < 200	Storage	5
E-1		Bench Floor Sink	16,700 6,700 > 330,000	190 750	General	< 2
F-1	100	Table Floor	3,300 5,000	< 100 < 100	Storage	2
G-1	750	Chair Sink Floor	6,700 13,400 (σ)	(σ) 10,000 (σ)	General	(σ)
H-2		General	(σ)	(σ)	General	< 2
I-2		General	(σ)	(σ)	General	< 2
J-2		General	(σ)	(σ)	General	< 2
K-2		General	(σ)	(σ)	General	< 2
L-2		Bench Floor	6,700 (σ)	(σ) (σ)	General	(σ)
M-2	6,000	Bench Floor	3,300 670	4,100 (σ)	Storage	10
N-3		General	(σ)	No data	General	(σ)
O-3		General	(σ)	No data	General	(σ)

[a]Type of facility:
1 - Operations include dial stripping or painting now or in the past.
2 - Operations include disassembly of instruments, but no dial stripping.
3 - Handles aircraft instruments, but does not disassemble instruments or strip dials.

[b]The floor of facility C has been covered recently with tile. The concrete under the tile is probably highly contaminated.

[c]Background.

Table 2. Removable alpha-particle contamination (long-lived) facility B, 1967

Date	Average contamination in locations shown below[a] (dpm/100cm^2)					
	A	B	C	D	E	F
May 24	< 10	90	30	40	< 10	< 10
May 29	70	300	800	2,100	100	< 10
June 5	30	70	30	< 10	< 10	< 10
June 12	200	700	30	2,000	15	< 10
June 19	20	130	30	500	< 10	< 10
June 26	50	400	30	500	< 10	< 10
July 3	30	700	30	20	< 10	< 10
July 10	50	150	20	10	< 10	< 10
July 17	30	500	40	10	< 10	< 10

[a]Locations:
A. Bench in old stripping area.
B. Floor in old stripping area.
C. Storage shelves.
D. Bench in instrument disassembly area.
E. General work area floor.
F. Office area floor.

Storage areas that were separate from the stripping area did not show any significant amount of fixed alpha-particle contamination. Dial refinishing areas showed some contamination which could be attributed to old silk screens and equipment that was used in the past when dials were painted with radium.

AIRBORNE HAZARDS

Air samples were collected on Hollingsworth and Vose Model 70 filters using the Eberline Model AIM-3 Air Monitor with a flow rate of 2.1 m^3/hour and the Eberline Model LAS-1 Air Sampler with a flow rate of 5.1 m^3/hour. The collection time was usually 8 hours or longer so that concentrations down to 10^{-13} μCi/cm^3 of long half-life alpha emitters could

be measured. The filters were counted with an Eberline Model AC-4 large area, gas-flow, proportional counter 5 days or more after collection so that only long half-life emitters were measured.

The airborne concentrations of long half-life alpha-particle emitters for facility B, which was doing a large amount of disassembly work during the study, but no stripping work, but no disassembly of instruments during the study, are given in tables 3 and 4, respectively. The concentrations measured in facility B were generally below 3×10^{-13} $\mu Ci/cm^3$ in all areas except the instrument teardown area that ranged up to 3.5×10^{-12} $\mu Ci/cm^3$. This is only 12 percent of the maximum permissible concentration for occupational exposure $(MPC)_a$, if we assume all of the alpha activity is radium 226. Since radium 226 would have associated with it some alpha-particle-emitting daughters, we can state that the concentration of radium 226 in facility B did not exceed 10 percent of the $(MPC)_a$ during the period represented in table 3.

Air samples from facility C (table 4) indicated higher airborne concentrations of long half-life alpha emitters than in facility B, but in no case did the concentration approach $(MPC)_a$ of 3×10^{-11} $\mu Ci/cm^3$ for radium 226. The maximum concentration measured was 7.4×10^{-12} $\mu Ci/cm^3$, which is 25 percent of the $(MPC)_a$ if we assume that all of the activity is radium 226 (no daughters).

Air samples were collected in facilities A and H over a period of several months. Concentrations of long half-life alpha-particle emitters in these facilities were generally below 1 percent of $(MPC)_a$ for occupational exposure. One sample collected during the decontamination of facility A (described under Decontamination Methods) indicated 1.4×10^{-12} $\mu Ci/cm^3$.

Table 3. Air sample concentrations of alpha-particles at facility B, 1967

Teardown area		Old stripping area	
Date	Concentration ($\mu Ci/cm^3$) x 10^{-12}	Date	Concentration ($\mu Ci/cm^3$) x 10^{-12}
June 26	3.5	June 27	0.1
July 5	0.1	June 28	0.2
July 6	0.0	June 29	0.1
July 17	0.6	June 30	0.1
July 18	1.0	August 7	0.2
July 19	0.7	August 10	0.0
July 27	2.6	August 11	0.1
July 28	0.7	August 12	0.0
July 31	1.0	August 13	0.1
Average	1.1	Average	0.1

Table 4. Air sample concentrations of alpha-particles at facility C, 1967

Date[a]	Location[b]	Concentration ($\mu Ci/cm^3$) x 10^{-12}
June 2	A	0.3
June 5	A	0.6
June 6	B	2.1
June 7	A	0.7
June 8	B	0.9
June 9	B	2.4
June 12	B	2.5
June 13	B	2.0
June 14	B	2.0
June 15	B	2.4
June 16	B	7.4
June 19	B	3.4
June 20	B	1.3
June 21	B	1.4
June 22	B	3.3
June 23	B	1.8
Average	B	2.5

[a]Samples were collected during working hours only.
[b]Location code:
A - Combination office and dial refinishing room
B - Dial stripping room

Radon film badges (6) worn for several months in facilities A, B, and H generally indicated less than 3×10^{-8} $\mu Ci/cm^3$, with none exceeding 1×10^{-7} $\mu Ci/cm^3$, the occupational $(MPC)_a$ for radon 222. Radon film badges worn in facility C gave an average concentration of 3.7×10^{-7} $\mu Ci/cm^3$ or almost four times the occupational $(MPC)_a$. A large number of radium dials were stored and stripped in facility C. This probably accounts for the higher levels measured in this facility.

Table 5. Employee exposure to radon gas - facility C

Exposure period	Hours[a]	Radon badge result (pCi-hrs/cm^3)	Concentration (pCi/cm^3)
April 1 to May 3, 1966	144	16.4	0.11
May 6 to June 8, 1966	184	7.2	0.04
June 9 to Aug. 1, 1966	304	22.8	0.08
Aug. 2 to Sept. 7, 1966	216	15.0	0.07
Sept. 8 to Oct. 7, 1966	200	149.0	0.75
Oct. 10 to Nov. 1, 1966	136	12.0	0.09
Nov. 2 to Dec. 13, 1966	240	48.0	0.20
Dec. 14 to Jan. 16, 1967	208	160.0	[b]0.77
Jan. 17 to Feb. 10, 1967	152	212.0	[b]1.40
Feb. 13 to Mar. 17, 1967	200	42.0	.21
Average			.37

[a]Based on a 40-hour week, 8-hour day
[b]At the time these badges were issued, badge contamination was a problem and may have biased these results.

EXTERNAL HAZARDS

Gamma-ray radiation levels above 2 mR/hour were frequently found in storage areas (table 1). The storage area was usually a drawer or box where dial faces were stored, or shelves where complete instruments were stored. Radiation levels to which a significant portion of the body could be exposed were generally 5 mR/hour or less with one exception; a drawer containing a large number of dials gave a reading of 13 mR/hour at 1 foot from the top of the drawer.

Significant levels of gamma-ray radiation were also encountered in areas where waste from the dial-stripping operation had accumulated. One waste drum from the decontamination of facility A had an exposure rate of 50 mR/hour at the surface of the drum. Most of the readings in the dial-stripping areas were due to the accumulation of paint and stripping solution in these areas.

Beta-gamma film badges were worn for 2 months in facilities A, B, and C; films were exchanged every 2 weeks. Beta-gamma film badges were worn in facility H for 6 months with monthly exchange. All of these badges showed less than 10 mR gamma-ray and less than 10 mrad beta-particle exposure. The film badge worn by the individual most directly involved in decontaminating the hood and gutter in facility A showed 70 mR of gamma and less than 10 mrad of beta-particle exposure. The probability of a worker in an aircraft instrument repair facility receiving a whole-body dose from beta or gamma radiation in excess of 500 mrem/year is very small.

INTERNAL HAZARDS

The mobile whole-body counting facility of Helgeson Nuclear Services, Inc., housed in an air-conditioned semi-trailer van, was used to determine the radium content of workers selected from each participating company (fig. 2).

The detector was an 8-inch diameter by 4-inch thick NaI (T1) crystal with a cesium 137 resolution of 7.6 percent. A shadow shield was used to reduce the background (fig. 3). Data was read out from a Nuclear Data Model ND130 AT512 multi-channel analyzer with a Varian X-Y recorder, an IBM computer typewriter and Tally tape punch (fig. 4).

Figure 2. The mobile whole-body counter semitrailer at the Wichita-Sedgwick County Health Department

Figure 3. A view of an individual entering the shadow shield of the mobile whole-body counter facility of Helgeson Nuclear Services, Inc.

Figure 4. Readout and analyser equipment of the mobile whole-body counter facility

The whole-body counter was located at the Wichita-Sedgwick County Health Department on July 5, 6, and 7, 1967, and employees of the participating companies were scheduled to report there for counting. Two individuals who had not worked with radium were counted as controls. All persons selected for whole-body counting showered carefully (including their hair) and put on clean coveralls. They were counted for 20 minutes. A Digital Equipment Corporation Model PDP-8/S computer was used to calculate body burden based on 30-percent retention of the radon gas from radium in the body (7). The results indicate that only personnel from facility C, a dial-stripping operation, contained body burdens of radium in excess of 20 nanocuries (table 6). The whole-body counting results in table 6 were based on the 1.76 MeV gamma ray but the positive results obtained for facility C were confirmed using the 2.19 MeV gamma ray.

Urine samples were collected and analyzed for radium. The results for these samples (table 6) were all less than 0.2 pCi/day at 95-percent confidence level, except for two samples from individuals at facility C. The radioactive material in these urine samples was positively identified as radium 226 by alpha spectrometry.

Table 6. Whole-body radium content of workers

Facility	Subject	Work code[a]	Exposure history where reported	Whole-body radium content[b,c] (nCi)	Urinalysis[c] (pCi/day)
A	1	F		5 ± 9	.03 ± .12
	2	E		9 ± 9	.03 ± .12
	3	B		6 ± 9	(d)
	4	F		3 ± 9	.01 ± .12
B	1	D		5 ± 8	(d)
	2	E	16 years	7 ± 8	.05 ± .12
	3	F	6 years - F 11 years - B	7 ± 8	.03 ± .12
	4	A	6 months	(d)	.08 ± .08
C	1	F,C		41 ± 10	.66 ± .20
	2	F		43 ± 10	.23 ± .12
	3	F	17 years	6 ± 9	.05 ± .12
	4	E,C		(d)	.16 ± .10
D	1	A		5 ± 8	(d)
	2	A		0 ± 8	(d)
	3	A		0 ± 8	(d)
	4	A	10 months	0 ± 9	(d)
	5	G		2 ± 8	(d)
	6	B		10 ± 10	(d)
E	1	B		6 ± 10	(d)
	2	H		2 ± 10	(d)
	3	A		2 ± 10	(d)
	4	A	14 years	14 ± 10	(d)
	5	F		6 ± 10	(d)
	6	B		3 ± 10	(d)
	7	G		10 ± 10	(d)
	8	B		3 ± 10	(d)
	9	E		3 ± 11	(d)
F	1	B	17 years	2 ± 9	(d)
	2	A		2 ± 9	(d)
	3	A		2 ± 11	(d)
M	1	C		7 ± 8	(d)
	2	A		9 ± 9	(d)
Control 1		-	None	10 ± 9	(d)
Control 2		-	None	6 ± 10	(d)

[a]Work code:

A. Instrument disassembler
B. General instrument technician
C. Paint stripper
D. Instrument receiving
E. Supervisory
F. Dial painter/refinisher
G. Janitorial
H. Engineering

[b]Content based on assumption of 30-percent body retention of radon.

[c]The error term for whole-body counting and urinalysis is the two-sigma (95-percent confidence level) counting error.

[d]Not counted.

CONTAMINATION GUIDES

One of the objectives of this study was to relate levels of radioactive surface contamination in aircraft instrument repair facilities to the radium body burdens of individuals working in these facilities. As noted above, only individuals working in facility C had detectable radium body burdens. Thus, the conclusions that can be drawn with regard to a correlation between radium surface contamination levels and internal body burdens are limited. The negative data does, however, allow one to draw the general conclusion that work under these conditions has not resulted in excessive internal exposure.

It is observed that facility C, which had the highest levels of contamination, also had the only individuals with detectable radium body burdens. It should be noted that the individuals in facility C had painted with radium luminous compound in the past and thus the source of internal body burden is uncertain. It is our opinion, however, that the contamination levels in facility C are unacceptable and probably contributed to the radium body burdens observed. Facility C had an average surface contamination of alpha emitters of 50,000 dpm/100 cm^2 based on 53 spot measurements. The next most highly contaminated facilities (A and B) had average contamination levels of about 8,000 alpha dpm/100 cm^2 (67 measurements in each facility).

Therefore, it appears appropriate to take 1/10 of the average contamination level of facility C or 5,000 alpha dpm/100 cm^2 to be an acceptable contamination guide. Since surface contamination levels are very variable within a facility, it is desirable from a practical standpoint to also set a guide for maximum levels of surface contamination. The arbitrary approach of using five times the average for maximum contamination gives 25,000 dpm/100 cm^2. It is our

recommendation that the guide for removable contamination be set at 1/10 of the guide for average contamination. These limits for maximum average and removable contamination appear consistent with the actual contamination levels observed in the study. The study also indicated that it was possible to keep contamination levels well below these values.

DECONTAMINATION METHODS

FACILITIES

Facility A was selected for evaluation of decontamination methods. The following decontamination plan was followed:

INITIAL SURVEY

The entire facility was thoroughly monitored for alpha contamination. Floors were monitored with the Eberline Model FM-3G Alpha Floor Monitor, which has an effective window area of 68 square inches and can monitor an area 21 inches wide with a single pass. Benches, storage shelves, hoods, hood exhaust stack, roof, and other areas that could not be monitored with the Eberline Model FM-3G were monitored with portable alpha counters, Eberline Models PAC-3G and PAC-4G. Wipe samples were taken and counted to indicate long-lived removable contamination. Areas of high contamination were marked on a floor plan of the facility. Areas where significant amounts of radium had accumulated (for example, the storage room, hood exhaust, sump in floor, and waste containers) were monitored with the Eberline Model E-500 Beta-Gamma Survey Meter. The survey equipment is shown in figure 5.

DECONTAMINATION OF HOOD

The hood was used to burn paint removed from instrument dials and organic solvent used in the stripping operation. This left a deposit of radioactive material in the hood and exhaust stack that varied from a very thin coat at the top to 1/4-inch thick at the bottom. This accumulation of radioactive material was removed in five steps, described below. The relative effectiveness of these methods is shown in table 7.

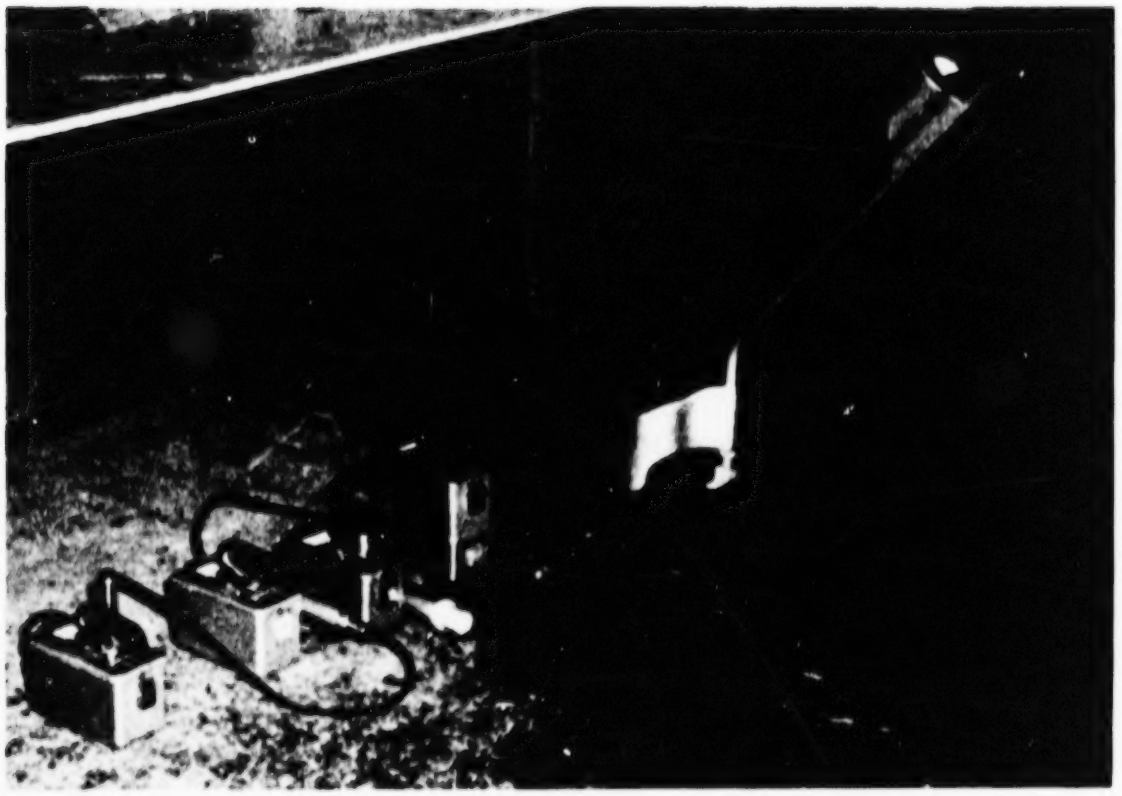

Figure 5. Portable survey equipment and floor monitor used in surveying aircraft instrument repair facilities

Method 1

A plastic bag was sealed with tape to each end of the exhaust stack. The stack was struck so that loosely ground material inside the stack would fall into the bag at the bottom of the stack. This method was not effective.

Table 7. Decontamination effectiveness - hood and exhaust stack

Location	Initial readings (dpm/cm^3)	Maximum readings after method indicated (dpm/cm^3)				
		1	2	3	4	5
Inside cap	1,000	1,000	300	200	100	(*a*)
1 foot down from cap	3,000	3,000	300	300	100	(*a*)
Inside stack just above hood	12,000	12,000	4,000	4,000	100	(*a*)
Inside stack at fan	10,000	10,000	5,000	(*b*)	(*b*)	(*a*)
Inside hood	20,000	20,000	10,000	9,000	5,000	1,500

[a]Not applicable
[b]This section was not accessible for methods 3 or 4.

Method 2

The stack was disassembled into three sections to permit better access. The material was removed from the hood and stack sections by scraping, then swabbed with paper towels wetted with various solvents. This procedure removed about 5 kilograms of debris which contained approximately 0.08 μCi/gram or about 0.4 nCi.

Method 3

The hood and each section of the stack were cleaned with a high-pressure spray containing Turco Decon 4324, mixed 8 ounces/gallon with water. This method was not effective. Turco Decon 4324 contains ammonia, carbonates, polyphosphates, wetting agents, and antifoam agents.

Method 4

Surfaces still contaminated were scrubbed using various materials wetted with Turco Kwik Solv, then method 3 was repeated. Turco Kwik Solv was more effective for this purpose than alcohol, mineral spirits or Turco Decon solvent. Kim-Pac seemed to be the best material for scrubbing. Others employed were Kleenex tissue, Modess sanitary pads and paper towels.

Turco Kwik Solv contains chlorinated hydrocarbons, wetting agents, inhibitors and anti-static agents. Turco Decon solvent contains petroleum solvents, chlorinated hydrocarbons, organic complexing agents, inhibitors, wetting agents and anti-static agents.

Method 5

Contaminated surfaces in the hood were scrubbed with muriatic acid (dilute HCl) using a stiff brush. This procedure was effective but left the bare metal exposed which rusted rapidly and required painting of the hood.

DECONTAMINATION OF PAINTED METAL TABLES

Metal tables were used during the stripping operation and had been painted prior to use. The tables were marked off in sections, and each section was covered with plastic film until it was uncovered for decontamination procedures. The relative effectiveness of various methods is shown in table 8.

Turco Decon 4512A diluted 1:4 with water was most effective. This material contains phosphoric acid, polyhydroxy organic acids, wetting agents, and inhibitors.

Table 8. Decontamination effectiveness - painted metal tables

Procedure	Maximum readings (cpm - π)	
	Before decontamination	After decontamination
Scrub with paper towels wet with alcohol	7,000	7,500
Scrub with paper towels wet with mineral spirits	25,000	25,000
Scrub with Kim-Pac[a] (packing material) wet with Turco Decon solvent[b]	5,000	400
Scrub with Kim-Pac[a] wet with Turco Kwik Solv[b]	7,500	600
Cover surface with Diverplus[c] allow to soak, then scrape with pancake turner	25,000	15,000
Scrub with a stiff brush using soap and water	7,500	7,500
Scrub with Radiac Wash[d] diluted 1:9 and a stiff brush	7,500	7,500
Cover surface with Turco Decon 4512A[b] diluted 1:4, allow to soak, scrape with pancake turner, then clean with Turco Kwik Solv[b,e]	15,000	200
Soak first for 15 min. with warm 20 percent Isoclean[f], then scrub with stiff brush, then spray with Turco Decon 4324[b] mixed 8 ounces/gallon	7,500	7,500

[a]Kimberly-Clark Corp., Neenah, Wis.

[b]Turco Products, Ind., Wilmington, Calif.

[c]A paint remover manufactured by the Diversey Corp., Chicago, Ill.

[d]Atomic Products Corp., Center Moriches, L.I., N. Y.

[e]This method was used to clean remainder of tables. Final survey gave 200 counts per minute (maximum).

[f]Isolab Supply Company, 665 West Bowery Street, (P.O. Box 3372), Akron, Ohio 44307.

DECONTAMINATION OF FLOORS

The entire floor was cleaned with an industrial vacuum cleaner, which was equipped with an absolute filter. The contamination was mostly fixed and no significant amount was removed by vacuum cleaning (table 9). The floor was marked off in sections to evaluate procedures B through I inclusive (table 9). Step C was performed on the same area as step B, and step G was performed on the same area as step F, since B and F were ineffective.

The most effective technique for painted concrete floors was damp mopping with Turco Decon 4512A diluted 1:4 with water. This same solvent was effective for indoor unpainted concrete floors, but a stiff brush was required. For unpainted outdoor concrete and for final cleaning of inside floors, muriatic acid scrubbed with a stiff brush was very effective. Muriatic acid may be purchased at a local drug store. Turco Decon 4512A and muriatic acid are strong acids and should be handled with caution.

DECONTAMINATION OF EQUIPMENT

Several items of equipment were found to be contaminated. No method was effective for all situations, but either Turco Kwik Solv or Turco Decon 4512A was effective for all but a few items.

FINAL SURVEY

After decontamination was completed, a final alpha-particle survey of the facility indicated that a few items were still contaminated above 2,500 disintegrations per minute/100 cm^2 maximum fixed, 1,000 disintegrations per minute/100 cm^2 average fixed, or zero removable contamination, which were the guidelines used for the study. These were discarded, cleaned further, or painted to fix the contamination. Floors and tables were generally below 2,500 disintegrations per minute/100 cm^2 fixed and 30 disintegrations per

Table 9. Decontamination effectiveness - floors[a]

Procedure	Maximum readings (cpm - w)		Decontamination factor
	Before decontamination	After decontamination	
A. Vacuum cleaning	6,500	6,500	1.0
B. Wet mopping with soap and water	6,500	6,500	1.0
C. Wet mop with Turco Decon 4512A diluted 1:4, then rinse with water (values for different areas)	6,500	750	8.7
	1,500	150	10
	1,200	300	4.0
D. Scrub with a stiff brush and Diverplus, then damp mop with water	20,000	7,000	2.9
E. Scrub with a stiff brush and Turco Decon 4512A diluted 1:4 then spray with Turco Decon 4324 at 8 ounces/gallon	9,000	250	36
F. Spray clean at high pressure with Turco Decon 4324 at 8 ounces/gallon	8,000	8,000	1.0
G. Soak 15 minutes with warm 20 percent Isoclean, scrub with a stiff brush, then spray with Turco Decon 4324 at 8 ounces/gallon	8,000	8,000	1.0
H. Scrub with a stiff brush and Turco Decon 4512A diluted 1:4 rinse with water (values for different floor areas)	8,000	750	10.6
	20,000	2,000	10
	9,000	2,500	3.6
	3,000	700	4.3
	23,000	3,000	7.7
	20,000	700	3
	20,000	5,000	4
	30,000	25,000	1.2
	40,000	2,000	20
Average, method H			7.4
I. Method H, followed by cleaning with muriatic acid and a stiff brush, rinse with water (values for different floor areas)	750	200	3.8
	2,000	400	5
	2,500	350	7
	700	400	1.8
	3,000	400	7.5
	700	250	2.8
	5,000	700	7.1
	25,000	7,000	3.6
	2,000	750	2.7
Average, method I			4.6

[a]Except as noted, all floors were unpainted or partially painted concrete.

minute/100 cm^2 removable. The average decontamination factors achieved were 25 for floors, 100 for highly contaminated benches and 15 for equipment. "Decontamination factor" is defined as the total radioactivity before contamination divided by the radioactivity after decontamination. In some cases the surface contamination levels increased as a result of the decontamination procedure. This apparently resulted from an uncovering of areas of higher contamination, or in the case of instrument parts and dials may be due to a transfer of activity from unaccessible to accessible surface areas.

Instrument Parts

A variety of instruments and instrument parts were used to determine the effectiveness of various noncorrosive solvents used in ultrasonic cleaners to remove the radium contamination (fig. 1). The ultrasonic cleaning unit was a Turco Model TU 1204 system with two tanks, one for the wash solvent and one for the rinse solvent (fig. 6). This system is rated at 600 watts total or 6 watts/square inch. Water circulating through a copper coil around the tanks kept the solution cool. In a few cases the solution was intentionally allowed to be heated to 75° C. (table 10).

None of the methods tried was consistently effective in removing radium contamination. The results reported in table 11 are average values based on four to seven groups of several instrument parts processed by each method. No definitive recommendation can be made as to a best method. Although method A (table 10) appears to be more effective, it is not recommended for all conditions, since the high value in table 11 results largely from one group of instruments. The decontamination of other groups of instruments by method A gave results similar to the other methods in table 10.

Table 10. Decontamination effectiveness - aircraft instrument parts

Method	Description of method	Decontamination factor[a]	
		Direct survey	Wipe
A	Ultrasonic cleaning, 1 minute in Turco Decon solvent, then 1 minute in Turco Kwik Solv.	14	18
B	Ultrasonic cleaning, 1 minute in Turco Decon solvent, then 1 minute in alcohol.	2	12
C	Ultrasonic cleaning, 1 minute in Turco Kwik Solv, then 1 minute in Turco Kwik Solv.	1	3
D	Ultrasonic cleaning, 2 minutes in chlorothene, then 2 minutes in Turco Kwik Solv.	1.1	4
E	Ultrasonic cleaning, 2 minutes in chlorothene, then 2 minutes in chlorothene.	1	1
F	Ultrasonic cleaning, 1 minute in cold perchloroethylene, then 1 minute in cold perchloroethylene.	1	2.6
G	Ultrasonic cleaning, 1 minute in hot (75° C.) perchloroethylene, then 1 minute in hot (75° C.) perchloroethylene.	1	1
H	Ultrasonic cleaning, 2 minutes in hot (75° C.) perchloroethylene, then 2 minutes in cold Turco Kwik Solv.	1.2	27
I	Ultrasonic cleaning, 2 minutes in Turco Decon solvent, then 2 minutes in Turco Kwik Solv.	2.2	1
J	Ultrasonic cleaning, 4 minutes in Turco Decon solvent, then 2 minutes in Turco Kwik Solv.	1	1
K	Ultrasonic cleaning, 2 minutes in Turco Kwik Solv, then 2 minutes in Turco Kwik Solv.	5	2
L	Ultrasonic cleaning, 4 minutes in Turco Kwik Solv, then 4 minutes in Turco Kwik Solv.	5	(b)

[a]Decontamination factor was obtained by dividing the total activity of several parts before decontamination by the total activity after decontamination.

[b]No data.

Contamination levels encountered on instrument parts, excluding dials, seldom exceeded 10,000 disintegrations per minute, and were generally less than 1,000 disintegrations per minute. Thus, the routine decontamination of all instrument parts, other than radium dials, is considered to have marginal value. If the control procedure includes precautions against spreading the contamination at the time the instrument is disassembled, the expense of cleaning all parts may not be necessary.

Dial Stripping

Careless methods in stripping dials containing radium account for the majority of the contamination on cables, sinks, floors, and walls in aircraft instrument repair facilities. In most of these facilities, the stripping operation could be discontinued without any significant economic impact. Only about 5 percent of the dials contain radium, and these can be replaced with new dials for approximately $2.00 each. Blanks for most dials can be purchased for less than $0.50 each. One quality control manager stated "We probably have enough instruments that do not have radium dials to take care of our requirements for a long time. We are thinking of removing all radium dial instruments from our inventory." If the entire industry could do the same thing, the radium problem would be greatly reduced.

1. Separate the radium dials from nonradium dials. Use separate equipment for cleaning the radium dials and keep the volume of waste small by using smaller containers.

2. Soak the dials in a mixture of 4 parts Diverstrip D-90 and 1 part Diverplus (Diversey Corp.) for 2 hours. Allow the paint to settle to the bottom of the container.

Table 11. Decontamination effectiveness - radium dials

Method	Description of method	Decontamination factor[a]	
		Direct survey	Wipe
A	Soak in Diverplus[b] 1 hour, scrub with stiff brush, rinse with water.	> 400	125
B	Same as A, except rinse with alcohol.	> 400	160
C	Same as A, except rinse with Turco Kwik Solv.	> 100	22
D	Same as A, except rinse with Turco Decon solvent.	> 500	50
E	Soak in Diverplus[b] 1 hour, rinse with water.	> 50	1,000
F	Soak in paint remover 1 hour, scrub with stiff brush, rinse with water.	(c)	(c)
G	Same as F, except rinse with alcohol.	(c)	(c)
H	Same as F, except rinse with Turco Kwik Solv.	> 100	550
I	Same as F, except rinse with Turco Decon solvent.	(c)	(c)
J	Soak in paint remover 1 hour, rinse with water.	(c)	(c)
K	Soak in Diverplus[b] 2 hours, dip in in Diverplus[b], scrub with towel, rinse with alcohol.	27	< 1
L	Soak in Diverplus[b] 2 hours, clean in Diverplus[b] with ultrasonics 2 minutes, rinse with alcohol.	> 600	15
M	Same as K, except rinse with Turco Kwik Solv.	1,000	300
N	Same as L, except rinse with Turco Kwik Solv.	10,000	220

[a]Decontamination factor was obtained by dividing the total activity of several parts before decontamination by activity after decontamination.

[b]The Diverplus solvent is made of 4 parts Diverstrip D-90 and 1 part Diverplus, both manufactured by Diversey Corp. The paint settles to the bottom when Diverplus solvent is used. This is an advantage in that the bulk of the contamination settles to the bottom with it.

[c]Not effective.

3. Remove the dial with tongs, being careful not to drip the contaminated liquid, and place it in a small ultrasonic cleaner containing 4 parts Diverstrip D-90 and 1 part Diverplus. The ultrasonic cleaner should be in a hood. Allow the dial to stay in the ultrasonic cleaner for 2 minutes.

4. Remove the dial with tongs, being careful not to drip the contaminated liquid, and rinse with Turco Kwik Solv into a third container.

5. Place the dial on an absorbent towel and allow to dry.

6. After each batch of dials is cleaned, transfer the contaminated solvents and paint residue into plastic bottles and pack in a plastic bag with enough absorbent to retain all of the liquid, in the event the bottle leaks. Discard bench paper and paper towels used to catch any dripping liquid along with the bottles of used liquid. They should be stored and discarded in plastic-lined 55-gallon drums. Label each drum as to the type of material (radium 226), the estimated amount, and the warning "CAUTION - RADIOACTIVE MATERIAL." The drum should be stored in an area marked "CAUTION - RADIATION AREA." Disposal must be made according to applicable State and U.S. Department of Transportation regulations.

INDUSTRY LIMITATIONS

The surveyed aircraft instrument repair facilities have not shown the willingness to decontaminate their facilities and establish effective control programs (table 12). An initial survey by the Kansas State Department of Health revealed extensive levels of contamination and the facilities were directed to decontamination and to initiate adequate radiation control programs. The survey 6 months later indicated no significant decrease in contamination levels. Many of the facilities surveyed had no instrumentation for detection of radiation. Only two had alpha instrumentation and three had beta-gamma instruments. In general, personnel working in these facilities have not received basic training in radiological safety or contamination control.

The disposal of waste from the dial-stripping operation is also a problem. Until recently the waste was burned in a hood, dumped on the ground outside, released to the sewer, or retained in a hold tank, and subsequently taken to the sewage treatment plant. Personnel at these facilities are not familiar with the U.S. Department of Transportation regulations pertaining to shipment of radioactive waste. Radium in the quantities accumulated by dial-stripping operations must be shipped either in containers specified by the U.S. Department of Transportation or under special permit from DOT. Most facilities need assistance in packaging, monitoring, labeling, and disposing of their radium waste.

The industry's ability to provide a reasonable radiation protection program is quite limited. The problem may be diminishing, however, in that most of the instruments worth rehabilitating have already had the radium dial replaced with a nonradium dial. Approximately 5 percent of the aircraft instruments in facilities surveyed contain radium dials. In many cases the dial-stripping operation can be eliminated

Table 12. Radiation and contamination levels in selected areas

	Facility A		Facility B		Facility C	
	Dec. 67	June 67	Dec. 67	June 67	Dec. 67	June 67
Alpha-particle contamination (dpm/100 cm^2)						
Maximum in stripping area	200,000	100,000	334,000	82,000	(a)	1,650,000
Average in stripping area	30,000	25,000	40,000	25,000	40,000	50,000
Maximum in other areas	5,000	5,000	167,000	82,000	167,000	33,000
Removable in stripping area	600	100	1,000	700	500	170
Removable in other areas	100	100	900	2,100	1,400	2,700
Gamma-ray radiation (mR/hour)						
Stripping area	60 (hood)	30 (hood)	< 2	< 2	5	5
Storage	5	5	< 2	< 2	13	13

[a]Not monitored in December 1966.

entirely without any serious economic impact, although removal of existing contamination in these facilities still presents a problem. Some facilities could accomplish this decontamination within their own capabilities provided they obtain suitable instrumentation. In other cases outside assistance and health physics consultation must be obtained.

RECOMMENDATIONS

1. Limits on contamination in aircraft instrument repair facilities should be set, based on total alpha activity, at 5,000 disintegrations per minute/100 cm^2 average fixed, and 500 disintegrations per minute/100 cm^2 removable. These limits are lower than those recommended by Duggan and Godfrey (*5*), but it is felt that they are attainable and appear to be safe based on whole-body counting of persons who have worked in this type of facility. Lower levels should be easily attainable in new facilities doing this type of work.

2. Dial faces containing radium and aircraft instruments containing radium dials should be segregated from those that do not contain radium. This can be done easily with a beta-gamma survey meter.

3. The stripping of dials containing radium paint should be discontinued in all facilities where suitable alternatives can be found. If dial stripping must be continued, the procedure recommended under "Decontamination Methods" (or a similar procedure) should be used.

4. Instrument disassembly should be done on a plastic sheet or bench paper, which can be rolled up and discarded when it becomes contaminated.

5. Urine samples should be collected from persons doing dial stripping at least once every year. If urinalysis provides a positive indication of radium in the body, and this result is confirmed by a resample, the person should be whole-body counted.

6. Air samples should be collected in areas where instruments are stored or disassembled or dials are stripped unless data over a period of several weeks indicate that concentrations in these areas are unlikely to exceed 10 percent of the maximum permissible concentration for occupational exposure.

7. Radium waste should be confined to as small a volume as practical. This waste should be packaged in plastic-lined metal drums. Liquid waste should be evaporated or packed with sufficient absorbent so that all the liquid would be absorbed if the primary container should leak. If an area within the State has been approved by the appropriate regulatory agency for disposal of radium waste, this facility should be used. If such a facility is not available within the State, a commercial waste disposal service should be encouraged to establish a collection and temporary storage facility within the State and provide assistance to each facility so that packaging, labeling, and shipping requirements of the U.S. Department of Transportation are met and special U.S. Department of Trnasporcation permits are obtained as required prior to interstate shipment.

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